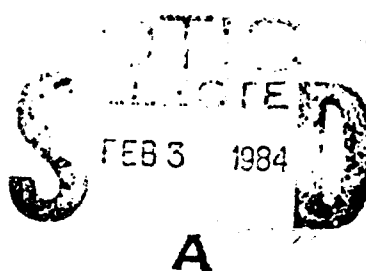


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**US Army Corps  
of Engineers**

Cold Regions Research &  
Engineering Laboratory

*Long-term plant persistence and  
restoration of acidic dredge soils with  
sewage sludge and lime*

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***Cover: Photo at left shows an eroded embankment along the Chesapeake and Delaware Canal. The embankments were subsequently seeded and treated with limestone, fertilizer and topsoil in September 1974. Photo at right is the same site in May 1976.***

# CRREL Report 83-28

December 1983

## *Long-term plant persistence and restoration of acidic dredge soils with sewage sludge and lime*

Antonio J. Palazzo

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20. Abstract (cont'd).

(*Lolium multiflorum* L. and *Lolium perenne* L.) were quickest, followed by K-31 tall fescue (*Festuca arundinacea* Schreb.), the red fescues (*Festuca rubra* L.), bentgrasses (*Agrostis tenuis* Sibth. and *Agrostis palustris* Huds.) and Kentucky bluegrasses (*Poa pratensis* L.). The ryegrasses and bentgrasses began to deteriorate 21 months after seeding and were not noticed on the site after 50 months. Grasses sown in mixtures with annual ryegrass were not as vigorous as those sown without it after 21 months, mainly due to the earlier aggressive growth and eventual lodging of annual ryegrass. Slight reductions in the ratings of K-31 tall fescue were also noted at this time and were partially related to lodging. This species had higher ratings in subsequent evaluations. Although establishing slowly, the Kentucky bluegrasses had high ratings after 21 months and through the remainder of the study. The red fescues performed well up to 50 months after seeding, but then declined. After 82 months the most persistent species were the Kentucky bluegrasses, K-31 tall fescue and the red fescues. Most treatments in this study had good soil cover after 82 months. As the study progressed, other species were able to dominate sites where less persistent species were sown. There were no continuing differences between varieties within species. The only difference in the chemical composition of selected plants sampled 50 months after seeding was the high concentrations of zinc in Pennlawn red fescue and phosphorus in K-31 tall fescue. After this time the red fescues received lower visual ratings, indicating a partial metal toxicity.

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## PREFACE

This report was prepared by Antonio J. Palazzo, Research Agronomist, Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. This research was originally funded by the Philadelphia District of the Corps of Engineers, with subsequent observations and revisions conducted under CWIS 31013, *Vegetation Restoration on Construction Sites in Cold Regions*. The author appreciates the technical support provided by J. Lakatos, W. Mueller and J. Radley of the Philadelphia District of the Corps of Engineers and J.M. Graham of CRREL. The Lofts Pedigreed Seed Co. and O.M. Scotts Seed Co. supplied seed for this study. The author also expresses his appreciation to C.E. Clapp, U.S. Department of Agriculture-Agricultural Research Service; R. Hurley, Lofts Seed Co.; C.R. Skogley, University of Rhode Island; and Barbara Gartner of CRREL for reviewing this report.

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# **LONG-TERM PLANT PERSISTENCE AND RESTORATION OF ACIDIC DREDGE SOILS WITH SEWAGE SLUDGE AND LIME**

**Antonio J. Palazzo**

## **INTRODUCTION**

Information on grass growth for long-term restoration of acidic dredge disposal areas and other disturbed lands is needed for developing strategies for establishing and managing vegetation. Restoring dredge disposal areas that contain pyritic soils is difficult because of their low pH, low organic matter content and general infertility (Fleming et al. 1974, Edgerton et al. 1975, Stuckey et al. 1980). In general, pyritic soils become highly acidic when brought in contact with the atmosphere (Jefferies 1981). Plants usually become established easier if the pH of the soil is raised and soil amendments are mixed into the soil to improve conditions for plant growth and to allow for deep root penetration (MacLean and Dekker 1976, Pinkerton and Simpson 1977, Sorenson et al. 1980, Stuckey and Zoeller 1980).

The use of sewage sludge to reclaim acidic dredge spoils may improve plant growing conditions by rapidly increasing the organic matter, fertility and pH of the soil (Cunningham et al. 1975, Palazzo 1977, Sutton 1979, Stuckey et al. 1980), but it also can add potentially toxic metals. Additions of lime will decrease the availability of metals in acidic soils (Palazzo and Duell 1974, Murray and Foy 1978, Stuckey et al. 1980), but large quantities of lime may be needed to reduce the acidity of pyritic soils (Sorenson et al. 1980). By adding lime and sludge together, it may be feasible to improve soil fertility to a level at which certain grasses can persist, thereby stabilizing the soil.

A potential problem in applying sewage sludge containing metals to low-pH soils is toxicity to

plants. In acidic soils, metals are both more available to plants and more susceptible to leaching. Copper, zinc and nickel appear to be the metals most likely to become toxic to plants when sewage sludge is applied to land (Webber 1972).

Chaney (1974) recommended that soils receiving sewage sludge be adjusted to and maintained at pH 6.5 or higher. Monitoring sites is important, since the soil pH can decrease after many applications of sewage sludge (Lunt 1959, Hinesly et al. 1971, Sutton 1979). Plants generally grow best in soils with a pH near 6.5. The tolerance of various grass species to low-pH soils has been reported by Spurway (1941), Musser (1962), Beard (1973), Palazzo and Duell (1974), and Murray and Foy (1978).

The objectives of this long-term study were 1) to determine whether applications of sewage sludge and dolomitic limestone could be useful as soil amendments and 2) to evaluate different grasses that may be suitable for restoring highly acidic dredged spoils. To be suitable the grasses must be able to survive and to stabilize soils, they must tolerate the toxic materials that may be in the sewage sludge or dredged material, and they must be able to persist with little management.

## **MATERIALS AND METHODS**

### **Soil amendment plots**

The dredge spoil discussed in this study was located along the Chesapeake and Delaware Canal in Delaware near Chesapeake City, Maryland. The experimental site was on the south side of the canal near the Summit Bridge. The spoil consisted

**Table 1. Composition of Wilmington sludge applied in July 1974.**

Element	Sludge composition (dry weight)	
	Mean	Range
Total N (%)	2.6	
Total P (%)	5.4	
Total K (%)	0.25	
Cr ( $\mu\text{g/g}$ )	9,584	5,560-12,890
Cu ( $\mu\text{g/g}$ )	2,772	1,290-4,654
Zn ( $\mu\text{g/g}$ )	3,470	2,186-4,230
Pb ( $\mu\text{g/g}$ )	1,327	724-2,520
Ni ( $\mu\text{g/g}$ )	227	140-311
Co ( $\mu\text{g/g}$ )	15.7	9.2-20.3
Cd ( $\mu\text{g/g}$ )	27.3	9.2-49.4

of acidic dredged disposal material that varied widely but was predominately a silt loam in texture. Three areas were studied: one treated with sludge and lime (sludge treatment); one treated with commercial fertilizer, topsoil and lime (fertilizer treatment); and one that did not receive any treatment (control).

Within the 6.6-ha sludge-treated area, sewage sludge and dolomitic limestone were applied during July and August 1974. Anaerobically digested primary sludge from Wilmington, Delaware, was initially placed on a sand filter drying bed. After drying, the sludge contained 21.5% solids. The sludge was trucked to the site and spread as uniformly as possible over the soil surface at a rate of 100 metric tons/ha on a dry weight basis. The average chemical composition of the sludge applied in July 1974 is shown in Table 1. The highest value for lead at Wilmington was above that noted in a review by Page (1974), while lead, chromium, copper and zinc were higher than those reported by Peterson et al. (1973). The high concentration of metals in the sludge indicates that industrial input was appreciable. After the sludge was applied, dolomitic limestone was broadcast at a rate of 23 metric tons/ha and was plowed to a depth of 20 cm.

The 20-ha fertilized area received applications of 13.8 metric tons/ha of dolomitic limestone and 550 kg/ha of 0-20-20 fertilizer and was tilled to a depth of 10 cm. We then applied 10 cm of topsoil to the site, which was tilled to a depth of 15 cm, intermixing the topsoil with the existing dredge spoil. Another 6.9 metric tons/ha of dolomitic limestone and 1320 kg/ha of 10-6-4 fertilizer were next applied to the site and tilled to a depth of 5 cm. The only application of fertilizer after seeding

was 660 kg/ha of 10-10-10 fertilizer applied to both sites in the fall of 1979.

Soils were sampled in November 1978 at three locations within the sludge-treated, fertilizer-treated and control areas at depth of 0-20, 20-40 and 40-60 cm. Samples were dried at room temperature (below 25 °C) in a drying cabinet and then crushed and passed through a 2-mm stainless steel sieve. Soil pH was determined at a 1:1 soil-water ratio, conductivity was determined at a 1:2 soil-water ratio, and organic carbon was determined by the Schollenberger method (Black 1965).

The atomic absorption spectrophotometer was used to analyze exchangeable and water-soluble calcium and magnesium; exchangeable and soluble magnesium and potassium were determined colorimetrically (Flannery and Markus 1971). Total metal and phosphorus were determined by boiling 2 g of soil for 2 hours with 15 ml of 70%  $\text{HClO}_4$ ; phosphorus was then determined colorimetrically and metals by atomic absorption spectrophotometry (Black 1965, Motto et al. 1970). Extractable metals were extracted by the DTPA procedure of Lindsay and Norwell (1978) and determined by atomic absorption spectrophotometry.

In September 1974 the sludge and fertilized sites were seeded with a drill seeder. The seed mixture and percentage by weight of each grass was: K-31 tall fescue (*Festuca arundinacea* Schreb.), 50%; Pennlawn red fescue (*Festuca rubra* L.), 40%; weeping lovegrass (*Eragrostis curvula* L.), 5%; and redtop (*Agrostis alba* L.), 5%. The seeding rate was 132 kg/ha. Hay mulch was applied at 2200 kg/ha.

Plant yields were taken from three 9-m<sup>2</sup> subplots in the sludge and fertilized areas in October 1978. The plants were cut at a height of 10 cm with a sickle bar mower and dried to constant weight.

#### Species evaluation plots

Within the sludge-treated area, a 500-m<sup>2</sup> site was used to evaluate grass species. This site was set up as a complete randomized block design and contained 87 individual plots with an area of 5.76 m<sup>2</sup> each. Eighteen grass species and varieties were sown alone or in combination (Table 2). The seeding rates and composition of each mixture are shown in Table 3. There were three replications of each of the 29 treatments.

In May 1975, May 1976, October 1978 and June 1981, approximately 9, 21, 50 and 82 months after seeding, general ratings of the grasses were recorded to assess their persistence and vigor. The 1975 and 1976 ratings have been reported previ-



**Table 2. Grasses included in the species evaluation plots.**

<i>Common name</i>	<i>Variety</i>	<i>Botanical name</i>
Kentucky bluegrass	common, Baron, Victa, Vantage and Merit	<i>Poa pratensis</i> L.
Red fescue	Jamestown, Highlight, Fortress, Pennlawn and Kensington	<i>Festuca rubra</i> L.
Tall fescue	K-31	<i>Festuca arundinacea</i> Schreb.
Annual ryegrass	common	<i>Lolium multiflorum</i> L.
Perennial ryegrass	common, Eton	<i>Lolium perenne</i> L.
Colonial bentgrass	Exeter	<i>Agrostis tenuis</i> Sibth.
Creeping bentgrass	Emerald	<i>Agrostis palustris</i> Huds.

**Table 3. Rates and composition of seed mixtures sown in the species evaluation plots.**

<i>Grass</i>	<i>Seeding rate (kg/ha)</i>	<i>Composition of mixture by weight (%)</i>
Baron Kentucky bluegrass	132	100
Victa Kentucky bluegrass	132	100
Vantage Kentucky bluegrass	132	100
Merit Kentucky bluegrass	132	100
Common Kentucky bluegrass	132	100
Jamestown red fescue	176	100
Highlight red fescue	176	100
Fortress red fescue	176	100
Pennlawn red fescue	176	100
Kensington red fescue	176	100
K-31 tall fescue	176	100
Common annual ryegrass	220	100
Common perennial ryegrass	220	100
Eton perennial ryegrass	220	100
Exeter colonial bentgrass	44	100
Emerald creeping bentgrass	44	100
Victa Kentucky bluegrass, Manhat- tan perennial ryegrass*	176	50,50
Vantage, Victa, common, Windsor Kentucky bluegrass†	176	45,30,15,10
Exeter, annual ryegrass	132	17,83
Exeter, Highlight	132	17,83
Exeter, Highlight, annual ryegrass	132	17,66,17
Exeter, K-31	132	17,83
Highlight, K-31	176	50,50
Highlight, Baron	176	63,37
Highlight, annual ryegrass	176	75,25
Highlight, K-31, annual ryegrass	176	38,38,25
Baron, K-31, annual ryegrass	176	25,50,25
K-31, annual ryegrass	176	75,25

\* Sports Turf

† Transition Blend

ously (Palazzo 1976). Also, in October 1978 the three replications of Baron Kentucky bluegrass, Jamestown red fescue and K-31 tall fescue from the sludged area were sampled for elemental analysis. The plant tissue was washed in distilled water, oven-dried at 60°C, and ground in a stainless steel Wiley mill using a 30-mesh sieve. Samples were wet-digested and analyzed for potassium, phosphorus, calcium and magnesium with an autoanalyzer according to the methods of Steckel and Flannery (1971). For metal analysis, the plant material was digested with a mixture of nitric and perchloric acid and then analyzed by atomic absorption spectrophotometry (Black 1965).

## RESULTS AND DISCUSSIONS

### Soil amendment plots

The dredged soils (control) were acidic (pH 2.4) and infertile (Table 4). Applications of dolomitic limestone, along with either sewage sludge or commercial fertilizer and topsoil, increased the soil fertility and pH to more optimal levels in the top 20 cm of soil. Only total soluble salts and exchangeable sodium (data not shown) were unaffected by either treatment.

Applications of sewage sludge significantly increased the organic nitrogen, total nitrogen and organic carbon over the fertilized treatments, which were similar to the control soil. The ferti-

Table 4. Mean fertility status at three depths four years after sewage sludge and fertilizer applications.

Soil characteristic	Control	Fertilizer plots			Sludge plots		
	0-20 cm	0-20	20-40	40-60 cm	0-20	20-40	40-60 cm
pH	2.4	4.7	3.3	3.0	4.8	3.1	3.6
Soluble salt (mmhos/cm)	1.22	1.44	2.79	2.70	1.49	2.10	1.25
Exchangeable cations (meq/100g)	1.86	20.29	31.24	25.64	18.78	1.70	24.44
Exchangeable Ca (meq/100g)	1.2	13.33	20.00	16.88	14.37	8.75	19.38
Exchangeable Mg (meq/100g)	0.51	6.69	11.04	8.50	4.26	2.83	4.82
Exchangeable K (meq/100g)	0.10	0.26	0.20	0.26	0.15*	0.12	0.24
Total N (%)	0.022	0.028	0.033	0.045	0.121†	0.034	0.034
Organic C (%)	1.0	0.9	2.1	1.8	2.6*	1.4	2.4
Total P (ppm)	215	859	443	387	1150	640	1233
Organic N (%)	0.022	0.028	0.033	0.044	0.121†	0.033	0.034

\* Values differ significantly at the 5% level within the 0-20 cm depth.

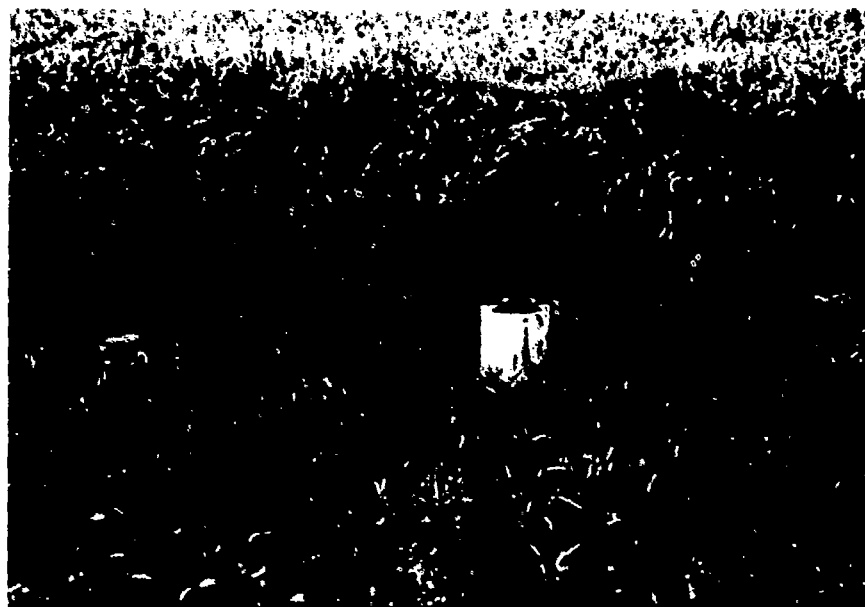
† Values differ significantly at the 1% level within the 0-20 cm depth.

Table 5. Total and extractible metal concentrations in soils (µg/g).

	Control	Fertilizer plots			Sludge plots		
	0-20 cm	0-20	20-40	40-60 cm	0-20	20-40	40-60 cm
Total							
Zinc	16.2	30.3	28.6	40.7	227.3†	46.2	55.0
Copper	4.4	4.0	5.7	4.9	94.3†	13.7	8.3
Chromium	32.4	39.7	24.7	46.7	132.7†	29.9	34.6
Lead	16.3	16.9	19.2	17.3	60.8†	20.0	23.1
Nickel	14.3	18.3	21.1	32.4	29.6*	36.0	30.3
Cadmium	1.6	2.0	1.9	2.3	3.2*	2.8	2.5
Extractible							
Zinc	1.3	2.3	1.3	0.9	66.3†	8.3	6.3
Copper	1.1	0.9	0.7	0.3	41.4†	3.6	1.6
Chromium	<0.1	<1.0	<0.1	<0.1	<0.1	<0.1	<0.1
Lead	<0.1	<1.05	<0.65	<0.10	25.5*	1.1	0.9
Nickel	1.2	1.3	1.7	2.09	5.4	11.2	8.7
Cadmium	<0.1	<0.1	<0.1	<0.1	0.78†	0.11	0.10

\* Values differ significantly at the 5% level within the 0-20 cm depth.

† Values differ significantly at the 1% level within the 0-20 cm depth.



*Figure 1. Growth of grasses one year after seeding. The grasses in the background were grown on a plot treated with sewage sludge; the grasses in the foreground were grown on a plot treated with commercial fertilizer and topsoil.*

lized soils contained higher contents of exchangeable potassium, which was related to the application of commercial fertilizers. The application of sewage sludge did not appreciably increase the potassium content of the soil. The 25-metric ton/ha application of dolomitic limestone was primarily responsible for the increase in soil pH and exchangeable calcium and magnesium in both the sludged and fertilized soils. Both applications greatly increased the amount of phosphorus.

At the lower soil depths the soils receiving fertilizer or sewage sludge were generally more fertile than the untreated or control soil (Table 4). This probably resulted from the downward movement of these soil components since soil incorporation, or tillage, occurred to a depth of only 20 cm. Within the sludged soils the pH, total nitrogen and organic nitrogen decreased with depth. Within the fertilized soils the pH and total phosphorus decreased with depth, while soluble salts, exchangeable cations, exchangeable calcium and magnesium, organic nitrogen, total nitrogen, and organic carbon increased. At the lower depths the fertilized soils were higher in soluble salts and exchangeable calcium and magnesium and lower in total phosphorus than the sludge soils.

The sludged soils contained greater amounts of total zinc, copper, chromium, lead, nickel and cadmium and extractable zinc, copper, lead and

cadmium than the fertilized soils (Table 5). There were significant differences in the extractable forms of chromium and nickel between the two soil treatments. Although the quantity of metals increased, the final concentrations were still within the range typically found in soils (Allaway 1968).

The greatest concentration of metals was in the top 20 cm of soil, or within the plow layer. Boswell (1975) and Williams et al. (1980) also found accumulations of metals near the soil surface.

The extractable forms of zinc, copper and nickel moved through the soil profile more than the total forms of these elements did (Table 5). Concentrations of extractable forms of zinc, copper and nickel were 4.4 to 7.2 times greater at the 20-40 and 40-60 cm depths in sludged soils than in fertilized soils. Increase in total metal concentrations only ranged from 0.9 to 1.7. Nickel was the only element in extractable form found to be in greater concentration at the lower soil depths. Only minor or no increases were observed at the lower soil depths for total and extractable chromium, lead and cadmium.

Plant yields were greater in plots receiving sewage sludge than those receiving fertilizer. The greater growth of grasses in the sludge area after one season is shown in Figure 1.



Figure 2. Species evaluation plots one year after seeding.

Table 6. Soil cover and heights of grasses in May 1975.

Grass	Soil cover (%)	Height (cm)
Kentucky bluegrasses	60-85	5-18
Red fescues	50-90	12-20
K-31 tall fescue	90	25
Common annual ryegrass	85	60-75
Common perennial ryegrass	90	30-45
Eton perennial ryegrass	90	20
Exeter colonial bentgrass	60	12
Emerald creeping bentgrass	50	5

#### Species evaluation plots

**Ratings.** Periodic ratings were taken of the various grasses sown in the species evaluation plots within the sludge area (Fig. 2). In May 1975, nine months after seeding, a preliminary visual analysis showed good seed germination and seedling vigor for all grasses tested, indicating that the amended soil could support initial plant growth (Table 6.). There were only small differences among varieties at this time (data not shown). The Kentucky bluegrasses provided fair to good soil cover. The fescues were considered acceptable, with both good cover and good color. K-31 tall fescue provided good cover and was taller than the red fescues and bluegrasses. The annual and

perennial ryegrasses were growing vigorously and were taller than all other species. Eton perennial ryegrass, an improved variety, developed a dense uniform vegetative cover and was not as tall as common annual or perennial ryegrass. The two bentgrass species had fair to good soil cover and were light green.

Of the seed mixtures tested during these preliminary ratings (data not shown), those that contained annual or perennial ryegrass developed a good vegetative cover (>95%). However, it was evident that the ryegrasses were tall, aggressive and overly competitive with all other species in this trial. All other mixtures studied gave fair to good soil covers.

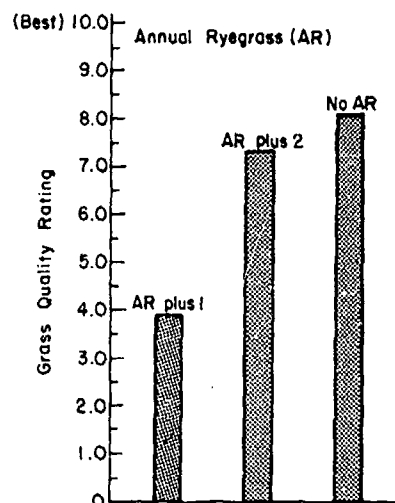
**Table 7. Quality ratings of species evaluation plots.**

Grass	Quality rating*	
	May 1976	Oct 1978
Common Kentucky bluegrass	6	8
Baron Kentucky bluegrass	8	9
Victa Kentucky bluegrass	9	8
Vantage Kentucky bluegrass	8	9
Merit Kentucky bluegrass	9	8
Jamestown red fescue	6	4
Highlight red fescue	8	5
Fortress red fescue	9	3
Pennlawn red fescue	9	3
Kensington red fescue	6	1
K-31 tall fescue	6	8
Common annual ryegrass	4	0
Common perennial ryegrass	5	0
Eton perennial ryegrass	5	0
Exeter colonial bentgrass	7	0
Emerald creeping bentgrass	7	0
Victa Kentucky bluegrass, Manhattan perennial ryegrass	6	7
Vantage, Victa, common, Wind- sor Kentucky bluegrass	8	8
Exeter, annual ryegrass	3	2
Exeter, Highlight	8	3
Exeter, Highlight, annual ryegrass	6	3
Exeter, K-31	7	7
Highlight, K-31	8	6
Highlight, Baron	9	8
Highlight, annual ryegrass	5	4
Highlight, K-31, annual ryegrass	5	6
Highlight, Baron, annual ryegrass	7	9
Baron, K-31, annual ryegrass	6	8
K-31, annual ryegrass	4	7
LSD <sub>0.05</sub> †	2	2

\* Quality rated from 0 = poorest to 10 = best.

† Least significant difference test at the 5% level of probability.

In May 1976, 21 months after seeding and after the plants had completed one full growing season, the grasses were again rated (Table 7). When the grasses were seeded alone, the Kentucky bluegrasses and red fescues produced a good soil cover, but there were differences among varieties. Common Kentucky bluegrass and Jamestown and Kensington red fescue received lower ratings than other varieties within their species. The ratings of the annual and perennial ryegrasses were relatively low, mostly due to lodging. Eton perennial ryegrass, which performed well earlier in the study, died out slightly and became spotty. K-31 tall fescue also had lower ratings due to lodging. The bentgrasses maintained fair to good soil covers.

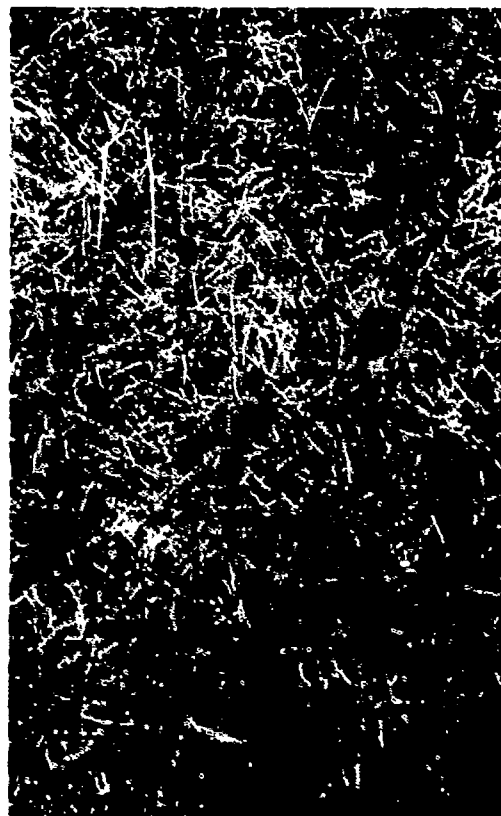


**Figure 3. Improvement in grass quality when reducing the amount of annual ryegrass in seed mixture.**

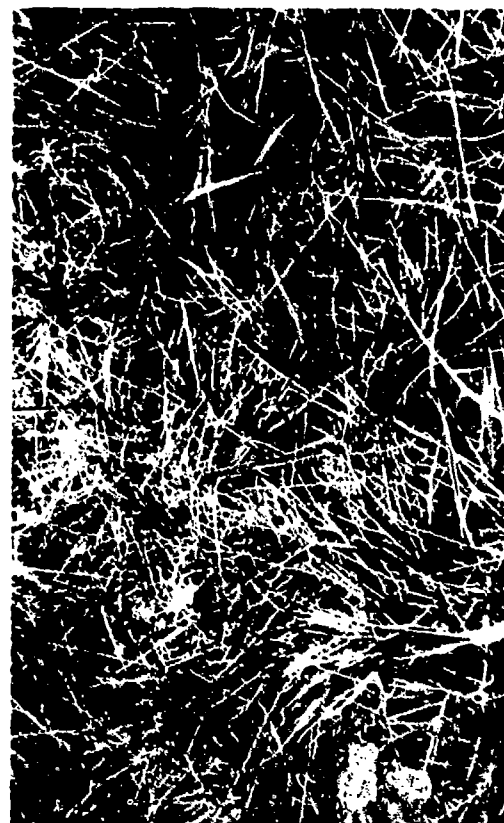
In a greenhouse study, Murray and Foy (1978) found that Highlight red fescue produced greater yields, on a dry weight basis, than Jamestown in soils with a pH of 4.6. They also observed that the yield of Victa Kentucky bluegrass was greater than Baron, which was greater than Vantage; the ratings of these varieties were in the same general order as in this study.

In May 1976 the mixtures containing annual ryegrass, which had done well earlier, received the lowest rating (Table 7, Fig. 3). The ryegrasses were overly competitive with the other species during establishment, and had lodged and were smothering the other grasses. These mixtures contained 25% by weight of annual ryegrass, or 44 kg/ha. Grasses in mixtures that did not include annual ryegrass were more vigorous and provided a good soil cover. Stuckey et al. (1980) also found decreases in the percentage of perennial ryegrass after a similar time on highly acidic mine spoils that were amended with sewage sludge.

In October 1978, 50 months after sludge application, the best ratings were for Kentucky bluegrass varieties and K-31 tall fescue, either alone or in mixtures (Table 7). There were no consistent differences among varieties within species. The bluegrasses were visibly shorter and provided the best soil cover, with an average rating of 8.3 (Fig. 4). K-31 tall fescue also provided good soil cover but was taller (Fig. 5). The soil surface in the plots containing tall fescue also contained greater amounts of litter, which had accumulated from the previous year's growth. The red fescues, which



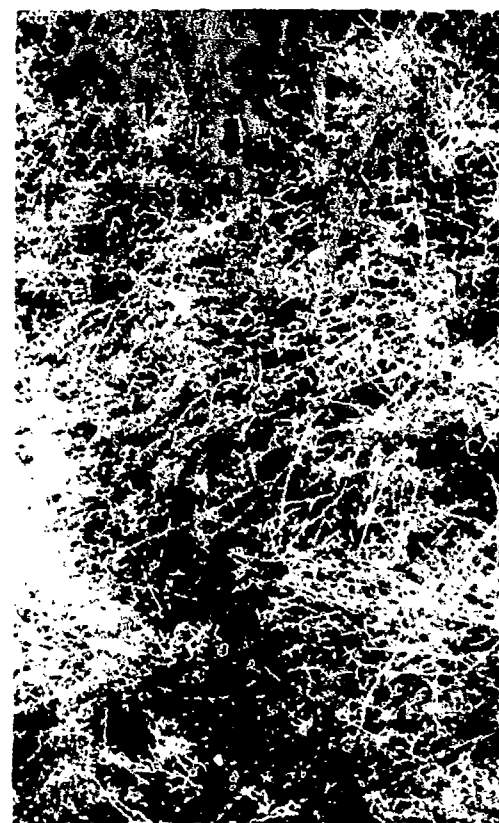
*Figure 4. Baron Kentucky bluegrass 50 months after seeding.*



*Figure 5. K-31 tall fescue 50 months after seeding.*



*Figure 6. Pennlawn red fescue 50 months after seeding.*



*Figure 7. Kentucky bluegrass 82 months after seeding.*

**Table 8. Mean percent soil coverage and species composition ratings, June 1981.**

Grass	Rating (%)	
	Total soil cover	Sown grass <sup>a</sup>
Kentucky bluegrasses (5)†	76	81
Red fescues (4)	62	22
Tall fescue (1)	70	53
Annual ryegrass (1)	78	0
Perennial ryegrasses (2)	59	0
Bentgrasses (2)	49	0
Mixtures including Highlight (7)	63	32
Mixtures including Baron (3)	73	64
Mixtures including tall fescue (5)	49	44
Mixtures including bentgrass (4)	63	0
Mixtures including annual ryegrass (7)	64	0

<sup>a</sup> Sown grasses = percent of total soil cover consisting of grasses sown in 1974.

† Numbers in parentheses indicate the number of varieties or mixtures used in determining rating.

**Table 9. Elemental analysis of grass samples in October 1978.**

Grass	N (%)	P (%)	K (%)	Zn (%)	Cu (%)	Cr (%)	Pb (%)	Ni (μg/g)	Cd (μg/g)
Baron Kentucky bluegrass	2.22 a*	0.28 b	1.60 a	131 a	10 a	11 a	5 a	2 z	0.5 a
Pennlawn red fescue	2.35 a	0.30 b	1.42 a	291 a	8 a	10 a	6 a	3 a	0.6 a
K-31 tall fescue	1.98 a	0.45 a	1.47 a	74 a	9 a	10 a	6 a	2 a	0.7 a

\* Concentrations of individual elements in columns followed by the same letter were not significantly different at the 5% level of probability according to the Duncan's Multiple Range Test (Little and Hills 1978).

had performed well during earlier ratings, did not rate as highly this time (Fig. 6). The grasses were clumpy and not as tightly knit as the soil cover produced by the Kentucky bluegrasses. The Pennlawn and Jamestown varieties, which had not performed as well earlier, received slightly higher ratings than the other red fescues. Perennial and annual ryegrasses and the bentgrasses had almost disappeared from the plots.

The site was again evaluated in June 1981, 82 months after seeding. The individual experimental plots containing less adaptable species (bentgrasses and ryegrasses) had been invaded by more adaptable grasses from neighboring plots. When sown alone or in mixtures, the Kentucky bluegrasses were the most dominant species in their plots and provided the best soil cover (Table 8, Fig. 7). They were followed by tall fescue and the red fescues.

**Chemical analysis.** In 1978, Baron Kentucky bluegrass, Pennlawn red fescue and K-31 tall fescue were sampled and analyzed. No significant differences were noted for any of the elements except phosphorus (Table 9). Baron Kentucky blue-

grass and Pennlawn red fescue contained significantly lower concentrations of phosphorus than K-31 tall fescue. Pennlawn red fescue contained higher, though not significantly different, concentrations of zinc than Baron Kentucky bluegrass and much more than in K-31 tall fescue. Pennlawn red fescue contained a mean zinc concentration of 291 μg/g, which is above the normal limits for plants (Allaway 1968) and could be a reason for the poor growth of this species. All other elements were in the range considered normal for plant growth (Allaway 1968), with the possible exception of potassium, which could be considered low (Martin and Matocha 1973).

## CONCLUSIONS

The dredge spoils in this study were low in soil pH and fertility. Applications of dolomitic limestone in combination with either sewage sludge or commercial fertilizer and topsoil improved conditions for plant growth at the site. These amendments increased soil pH, phosphorus and ex-

changeable calcium and magnesium. Sludge applications increased soil exchangeable potassium. Exchangeable sodium and total soluble salts were unaffected by the treatments.

Sludge applications increased the metal concentrations of soils but not to excessive levels. The greatest metal concentrations were within the plow layer (the upper 20 cm of the soil profile). Below this depth, only the concentrations of the extractable forms of zinc, copper and nickel were increased.

In the species evaluation plots the ryegrasses became established more quickly than the other grasses studied. This was due to their rapid germination and development rates. K-31 tall fescue established more rapidly than the red fescues, which were quicker than the Kentucky bluegrasses.

After 21 months the Kentucky bluegrasses and red fescues, seeded alone or in combinations not including ryegrasses, were the most desirable species for providing the best soil cover. At this time the ryegrasses had lodged and partially smothered other grass species. The bentgrasses maintained a fair to good soil cover early in the study but did not persist.

All varieties of Kentucky bluegrasses and red fescues performed equally well, except for common Kentucky bluegrass and Jamestown and Kensington red fescue, which received lower ratings. K-31 tall fescue also lodged because of its previous rapid growth and received lower ratings than the red fescues and bluegrasses.

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